Biofuels: implications for agricultural water use

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Abstract

Rising energy prices, geopolitics and concerns over the impacts of green house gas emissions on climate change are increasing the demand for biofuel production. At present biofuel production is estimated at 35 billion liters, accounting only for a small part of the 1200 billion liters of annual gasoline consumption worldwide. But the contribution of biofuels to energy supply is expected to grow fast with beneficial impacts including reductions in greenhouse gasses, improved energy security, new income sources for farmers and greater energy efficiency compared to fossil fuels. However, biomass production for energy will also compete with food crops for scarce land and water resources, already a major constraint to agricultural production in many parts of the world. China and India, the world's two largest producers and consumers of many agricultural commodities, already face severe water limitations in agricultural production, yet both have initiated programs to boost biofuel production. This paper explores the land and water implications of increased biofuel production globally and with special focus on these two important countries, using the WATERSIM model. It concludes that even if aggressive plans to increase biofuel output come to fruition, they will have relatively minor impacts on the global food system and water use. However, local and regional impacts could be substantialIn fact, the strain on water resources would be such in China and India that it is unlikely that policy makers will pursue biofuel options, at least those based on traditional field crops.

1) Introduction: Energy and water

Fluctuating energy prices affect agriculture, and thus agricultural water management, in different ways. The potential impact of higher energy prices on agricultural water use is fourfold. First the demand for cheaper energy sources, including hydropower and energy from biomass rises, increasing water demand and changing water resource allocation. Second, the cost of pumping groundwater, a major factor in agricultural production around the world, increases. In addition, energy for groundwater use in some parts of the world, most notably India, is subsidized Rising energy prices thus put additional pressure on government budgets and may lead to rising costs to farmers. In the Indian context this means, making irrigation unaffordable to millions of small farmers; Third, when energy prices rise, the viability of desalinization as a source of irrigation and other water supply declines. Finally, fertilizer prices and the unit costs of other oil-based inputs rise with increases in energy prices.

Both hydropower and biomass require substantial amounts of water. Hydropower is largely a non-consumptive water user though there are some consumptive losses through evaporation from reservoirs and timing of releases may conflict with other consumptive uses. The production of biomass, on the other hand, is a consumptive use of water that may compete directly with food crop production for water and land resources (Berndes 2002). At present the role of biomass in meeting energy demand is modest. Only 7% of total global energy supply comes from biomass mainly wood, crop residues, and dung (IEA 2004a). Regional variation is substantial: in sub-Saharan Africa, where fire wood for cooking is widely used, close to 60% of energy use comes from biomass, while in OECD countries the portion is only 2%[1].

With concerns over high energy prices, volatility of oil supply and greenhouse gas emissions, energy derived from biological sources and in particular biofuels have received considerable attention (see for example IEA 2004a, IEA 2004b, Dufey 2006). Particularly fast growing oil importing economies such as China and India are exploring

[1] Note that there is a difference between the broad term bio-energy (used in households, transport an industry) and the much more limited term biofuels, used as transport fuels for cars, buses and trucks.

biofuels to curb oil dependency. But to grow biofuel crops more land and water will be needed. Both China and India already suffer from water scarcity problems that will only worsen as their food demand continues to grow with rising populations and incomes.. China is implementing a costly transfer project to bring water from the water-abundant South to the water-short North. India is exploring the possible implementation of a controversial multi-billion dollar project of inter-basin water transfers, to meet future demands. In both countries and other water scarce areas biofuels will add pressure to already heavily exploited water resources. This paper looks into implications of biofuel production on water use, with emphasis on China and India.

2) Biofuels production and use

Biofuels are transportation (or heating) fuels derived from biological sources such as grains, sugar crops, oil crops, starch, cellulosic materials (grasses and trees) and organic waste. There are two main types of biofuels: bioethanol and biodiesel[2]. The production of bioethanol, made from sugarcane, corn, beets, wheat, and sorghum, was estimated at 32 billion liters in 2006. Brazil (using sugarcane) and the USA (using mostly corn and some soya) are the main producers, accounting for 70% of the global supply (Dufey 2006). Biodiesel production, derived from oil- or tree-seeds such as rapeseed, sunflower, soya, palm, coconut or jatropha, was estimated at 2 billion liters in 2005 (IEA 2004). Three countries in Europe (Germany, France and Italy) produce nearly 90% of the global supply, primarily using rapeseed (Dufey 2006).

Together, bioethanol and biodiesel account only for around 2% of the global annual consumption of 1200 billion liters of gasoline (in energy equivalents[3]) (Dufey 2006). However, the contribution of biofuels to energy supply is expected to expand rapidly. Global bioethanol production doubled between 1990 and 2003, and has been projected to double again by 2010. In some regions, especially Europe, biodiesel fuel use

[2] Both are typically mixed with conventional car fuel gasoline and diesel respectively, so called flex-fuel. Blends vary between few percent of biofuel to nearly 25% in Brazil.
[3] The energy content of one liter of biofuel depends on the type but is typically estimated at 65% of that of fossil fuel (see also http://bioenergy.ornl.gov/papers/misc/energy_conv.html).

has also increased substantially in recent years (IEA 2004a). At present the biofuel supply and demand is dominated by the few big producers mentioned above (Brazil, USA and EU). But interest is rising among many countries around the world, and many have put policies in place to spur biofuel production and use (IEA 2004a).

Reasons to promote biofuels

Biofuels have been part of the energy discussions for decades. However, over the past few years, discussion, and action, has increased with rises in crude oil prices. But leaving prices aside, there are a number of reasons why governments are showing interest in biofuels even when subsidies are needed for them to be commercially viable. These include energy security, concerns about trade balances, desires to decrease greenhouse gas emissions and potential benefits to rural livelihoods (Dufey 2006).

1) Energy security - The volatility of world oil prices, uneven global distribution of oil supplies (75% in the Middle East), uncompetitive structures governing the oil supply (i.e. the OPEC cartel) and a heavy dependence on imported fuels leave oil importing countries vulnerable to supply disruption (Dufey 2006). Recent interruptions in oil supply from Russia to Belarus because of political disagreements acutely illustrate this vulnerability. Biofuels are often seen as part of a strategy to diversify energy sources to reduce supply risks.

2) Trade balance – Poor oil importing countries spend a large part of their foreign currency reserve to buy oil. Producing biofuels to substitute oil imports helps reduce the oil bill[4].

3) Greenhouse gas emission reduction – many studies indicate that the use of biofuels reduces GHG emission as compared to fossil fuels (IEA 2004) though the extent of reduction is disputed and depends on crop and production technology (Sims et al. 2006, Farrel et al. 2006). Some studies indicate that biofuel production generates more GHG than it saves in burning (Pimentel 2003).

[4] For example Boyle (2005) cites an unofficial estimate that Brazil's ethanol program saved the country US$ 18 billion foreign exchange over the period 1979-90. Langevin (2005) cites a number of US$ 1.8 billion per year between 1976 and 2000.

4) Rural development and income generation - Biofuels generate a new demand for agricultural products, creating jobs in rural areas and increases in farmer income through higher commodity prices[5].

However, compared to fossil fuels biofuels are still relatively costly (IEA 2004) though with the introduction of new more efficient techniques -such as the use of yeast (Alper et al. 2006) and enzymes to produce lignocellulosic bioethanol - production costs may come down in coming decades. The oil price that would make biofuels competitive depends on many factors, including changes in the cost of producing, transporting and processing biomass. Estimates show that bioethanol in the EU becomes competitive when the oil price reaches US$ 70 a barrel while in the US it becomes competitive at US$ 50 - 60 a barrel and in Brazil between US$ 25 and US$ 30 a barrel. Other efficient sugar producing countries such as Pakistan, Swaziland and Zimbabwe have production costs similar to Brazil's (Petroleum Economist 2005, Dufey 2006). A further possibility is that biofuels could become competitive if they are used to offset greenhouse gas emissions (Parikh and Gokarn 1993). At present, the development and promotion of biofuels are mainly driven by the agricultural sector and green lobbies rather than energy sector (IEA 2004a). In fact, most biofuel programs depend on subsidies and government programs, which can lead to market distortion and is costly for the government[6]. Nevertheless at sustained high oil prices and with a steady progression of more efficient and cheaper technology, biofuels could be a cost-effective alternative in near future in many countries.

Concerns of rapid biofuel growth

But there are important implications of a possible large scale development of biofuel. Two often raised concerns relate to impacts on water and land resources and competition for food.

1) Environmental impacts – biofuels require additional land and water resources. The Millennium Ecosystem Assessment claims that agriculture already is the largest factor in

[5] Moreira (2005) estimates that sugarcane in Brazil (which directly relates to bio-ethanol production) employs 1 million workers.

[6] The US paid 2 billion dollar of subsidies to produce 16 billion liters of biofuel (Kammen 2006). That is o subsidy of 13 dollar cent per liter

ecosystem modification (Alcamo et al. 2005). With growing population and rising income, pressures on natural resources will intensify, leading to more loss of natural habitat. Further, water scarcity already is a limiting factor in food production in many regions (Molden et al, forthcoming). Biofuel crops such as sugar are water intensive, often under monoculture, leading to increased water scarcity and water pollution. With increasing population, incomes and urbanization, water demand will rise and recent forecasts warn of impending global problems unless appropriate action is taken to improve water management and increase water use efficiency (Seckler et al. 1998, Rosegrant et al. 2002). Already 1.2 billion people of the global population live in areas where water is scarce even today (Molden et al. forthcoming). To meet future global food demand by 2050, irrigation withdrawals may have to increase another 20%, even under an optimistic productivity scenario (Fraiture et al forthcoming). Water for biofuels will add pressure on water resources that already are stressed –or will soon be - in many places.

2) Competition with food – There are also concerns that with increased demand of biofuel crops competition for limited land and water resources will raise agricultural commodity prices. Rosegrant et al (2006) foresee substantial price increases in cassava, sugar, oilcrops and grains. Brown (2006) attributes recent corn price increases in the US to increased demand due to new biofuel plants. China lowered its ethanol targets after corn prices increased by 7% and other grain prices also increased allegedly due to increased demand from biofuel plants (ChinaNews, AFP 2006). Higher food prices will adversely affect the urban and landless poor. Pimentel (2003) –among others- rejects the use of food crops for energy in a world where hunger persists, on ethical grounds. Others claim that land and water resources are sufficient, so that there will be no direct competition between food and fuel, except possibly in the very short term. Current low commodity prices point to a surplus production capacity. Higher food prices will actually help poor farmers in developing countries who suffer from policy induced food surpluses in the US and Europe dumped on the world market[7].

[7] (see Green Room BBC, Farmer representative).

3) Present land and water requirements

Land

At present the amount of land and water resources devoted to biofuel crop production is modest at 11 to 12 million hectare, around 1% of the total area under crops (Table 1). In Brazil, the biggest bioethanol producer, 2.5 million ha (5% of the cropped land) is used for biofuel production, with a production rate of 6200 liters of ethanol per hectare, mostly from sugarcane. The USA, the second biggest ethanol producer, allots nearly 4 million hectares to biofuel crops (4% of the total cropped area), with yields of roughly 3300 liters per hectare, mostly from maize. Using the data and conversion ratios listed in table 1, we estimate that the global average ethanol production from one hectare of land is around 3500 liters. This is consistent with estimates by International Energy Agency (2004a). In Europe, where biodiesel is the main product made from rapeseed, one million hectare is used, yielding on average 1700 liters of biodiesel per hectare.

[insert table 1 somewhere here]

China is now becoming a major player in biofuel production, ranking among the world's top three ethanol producers. In 2002 it produced 3.6 billion liters of bioethanol in 2002 of which 76% was derived from maize (ChinaNews, AFP 2006). At prevailing yields and conversion factors this corresponds with nearly 2 million hectares of land, or only 1% of the total cultivated area. Production in India is roughly half that of China but also projected to grow rapidly. Present bioethanol production is 1.7 billion liters, derived predominantly from sugarcane. India is now also actively promoting biodiesel from Jatropha, a tropical tree based oilcrop. Jatropha can produce up to 1500 liters of biodiesel per hectare in the most favorable soil and water circumstances, though usually it produces much less (Mkoka and Shahanan 2005). Because the trees can grow on marginal land with limited water and its seeds are non-edible, it does not compete directly with food (in terms of land and water resources). Together sugarcane, Jatropha and other crops for biofuel production occupy only 0.3% of India's total cultivated area.

Water

Globally around 7130 km^3 of water is evapotranspirated by crops per year, without accounting for biofuel crops (Molden et al, forthcoming). Biofuel crops account for an additional 100 km^3 (or around 1%). In terms of irrigation water the share is slightly higher because of the relatively large share of irrigated sugarcane in the biofuel mix. Total irrigation withdrawals amount to 2630 km^3 per year globally (ibid) of which 44 km^3 (or 2%) is used for biofuel crops. It takes on average roughly 2700 liters of crop evapotranspiration and 1200 liters or irrigation water withdrawn to produce one liter of biofuel. But regional variation is large. In Europe where rainfed rapeseed is used, the amount of irrigation for biofuel crops is negligible. In the US, where mainly rainfed maize is used, only 3% of all irrigation withdrawals is devoted to biofuel crop production, corresponding to 400 liter of irrigation water withdrawals per liter of ethanol. On the other hand in Brazil where the main biofuel crop – sugarcane – is partly irrigated, nearly half of the irrigation withdrawals are used for ethanol production. China withdraws on average 2400 liters of irrigation water to produce the amount of maize for one liter of ethanol. Around 2% of total irrigation withdrawals in China is for biofuel crop production. With high sugarcane yields and conversion efficiency Brazil requires 1150 liters of irrigation withdrawals for every liter of ethanol production. In India where yields and conversion efficiencies are lower and sugarcane is fully irrigated, water withdrawals for every liter of ethanol are nearly three times higher at 3500 liters.

4) Role of biofuels in future energy

Future energy and the role of biofuels

Future energy use depends on many factors, but the main are GDP growth and price of energy. Though both factors are very hard to predict, it is likely that China's and India's economies, and thus oil demand, will continue to grow rapidly. The International Energy Agency (IEA) foresees a growth in global oil demand of 60% from 4500 billion liters per year in 2002 to 7700 billion liters in 2030. China and India alone will be responsible for 68% of this increase (IEA 2004b). Oil demand for transport is an important component of oil demand. In 2002 the OECD used 30% of its oil product supply for motor gasoline, the

USA more than 40%. In non-OECD countries where private car ownership is less common the share is smaller. For example, in China this percentage is 17% (IEA 2005). Globally, gasoline demand is now estimated at 1200 billion liters per year (Dufey 2006). We use those estimates combined with information on country policies and targets as basis for our assessment of potential impacts of increased biofuel production on water use.

Table 2 provides an overview of assumptions on the future share of biofuels, consistent with the expectations of the International Energy Agency (IEA 2004a) and Rosegrant et al (2006).. Under a scenario where biofuels are actively promoted by government support, the share of demand may reach 7.5% of total gasoline demand globally, equivalent to 140 billion liters by 2030; a near quadrupling relative to the base year.

[Insert table 2 somewhere here] Table 2: Use of gasoline and biofuel

<u>Future biofuels in China:</u>

With oil consumption more than doubling, China's oil import dependence will increase dramatically from 34% now to 70% in 2030 (IEA 2004b). Energy consumption in road transport is expected to grow by 5% annually over the coming decades, though projections vary by an order of magnitude depending on assumptions on GDP, car ownership, mileage, and policy scenarios (Schipper et al, no date). To curb oil dependency, air pollution and greenhouse gasses emissions and support rural economies, China has set a goal of producing 6 million tons of cleaner-burning substitutes to coal and oil by 2010 and 15 million tons by 2020 (ChinaNews AFP 2006), In 2020 this is equivalent to 18 billion liters of gasoline energy equivalent, or 9% of projected gasoline demand.

Though recently the growth in ethanol production slowed over fears of increased maize prices, in our bio-fuel scenario we assume a 9% share by 2030, which is consistent with Rosegrant et al (2006), implying a five fold increase over 2002.

Future biofuels in India

Oil demand in India is expected to grow by a factor 2.2 by 2030, increasing the oil import dependency from 69% now to 91%. With the number of vehicles doubling between 2002 and 2020 (IEA 2004b), gasoline demand will make up a substantial part of this increase. The Indian Planning Commission has therefore proposed a program to produce ethanol to be blended with gasoline, and biodiesel to be blended with highspeed diesel. The ethanol is primarily derived from sugarcane and diesel from the tree based oilcrop Jathropa. The policy of 5% blending of gasoline with ethanol was made compulsory in 2003 in 9 states, but due to high costs and red tape the measure was recently abandoned in most of them (Padma 2005). The Planning Commission also intends to blend highspeed diesel with 20% Jatropha based biodiesel by 2012 (TERI, 2003). The Indian government's Vision 2020 document states that cultivating ten million hectares with jatropha would generate 7.5 million tonnes of fuel a year, creating year-round jobs for five milllion people. But despite ambitious programs, targets are likely to be missed due to the high costs of Jatropha based fuel and red tape (Padma 2005). In our biofuel scenario we assume that 10% of the gasoline demand in 2030 will be met by sugar based bioethanol (in energy equivalents), requiring 9 billion liters, an increase by a factor 4.7 compared to 2002. This is in line with estimates by IEA (2004a) and Rosegrant et al (2006). The role of Jatropha will likely remain small until major technology breakthroughs are realized. In addition, Jatropha production doe not generally compete with food crops for land and water, in particular irrigation water.

5) Implications for water

What are the implications for land and water resources of a quadrupling biofuel production? To what degree will this compete with food crops for water and land resources? To address these questions we compare actual and projected land and water use for food production with and without additional demand for biofuels. As a baseline to simulate water and food demand for agriculture without biofuels, we use the base scenario developed for the Comprehensive Assessment of Agricultural Water

Management (Fraiture et al. forthcoming)[8]. This optimistic scenario assumes a combination of strategies to meet food demand while minimizing additional water requirements. Those strategies include improving rainfed agriculture through better rainwater management, improving yields and water productivity on existing irrigated areas, and expanding irrigated areas and trade, according to regional strengths and limitations. One of the conclusions of the Comprehensive Assessment of Agricultural Water Management is that water resources are sufficient to meet food security, poverty reduction and environmental goals simultaneously, provided the right policy and investment measures will be taken (Molden et al forthcoming). However, bioenergy crops were not included in the analysis.

Food, biofuels, land and water

Our baseline scenario foresees that by the 2030 global maize supply will reach to 890 million tons to meet food and feed demand, an increase of 40% compared to 2005. Most of this increase stems from higher feed needs to meet increased meat demand, a result of higher incomes. Sugar production will rise to 2460 million tons of cane, up by 35% from the base year, again mainly due to dietary changes stemming from income growth. Assuming no changes in feedstock[9] and conversion efficiency, biofuels will require around 180 million tons of maize, 525 tons of raw sugarcane and 50 tons of oilcrops. These amounts are 20%, 25% and 80%, respectively, above baseline scenario production (Table 3).

[Insert table 3 somewhere here] Table 3: Biofuels and feedstock (% of food)

On a global level the biofuel scenario requires 30 million additional hectares of cropped area (compared to 1400 million hectares for food crops), 170 km^3 additional ET (compared to 7600 km^3 for food) and 180 km^3 more withdrawals for irrigation (compared to 2980 km^3 for food) (Table 4). While for individual crops increases may be substantial, compared to the sum of all crops increases are modest. These figures amount to increases

[8] Scenarios are quantified using the WATERSIM model (see Fraiture 2006)
[9] Feedstock is the crop or biomass type used to derive biofuel

in resource use in the order of only 2 to 5% more, levels too small to lead to major changes in agricultural systems at a global level.

[Insert table 4 somewhere here] Table 4: Water and land requirements

But on country level a different picture emerges. China needs to produce 26% more maize and India 16% more sugarcane above the base scenario levels. This means 35.1 km3 and 29.7 km3 of additional irrigation water in China and India respectively. while both countries already face serious water shortages.

China's water and scope for further development (or the lack thereof)

Irrigation plays a dominant role in China's food production. An estimated 75% of total grain production, 90% of vegetables and 80% of cotton comes from irrigated areas. About 70% of total wheat and 60% of total maize are harvested in the Northern region (i.e. the Yellow, Huaihe and Haihe river basins), where more than 60% of the area is irrigated and groundwater resources are already extensively overexploited (Liao 2005). The South imports food from the water stressed Northern region and the international food market (Zhou et al. 2005). Earlier the water rich South produced a surplus that was exported to the Northern provinces. But with economic development and associated higher opportunity costs for land and labor, agricultural production in the developed South is becoming less attractive to farmers who have more opportunities to work in non-agricultural sectors (Liao et al. 2007).

The total volume of water resources in China ranks sixth worldwide, but per capita supplies are only 2200 m^3 in 2000, about 1/4 of the world average. Particularly, in the North -Haihe, Huaihe and Yellow river basins- per capita water resources are low, only 290 m^3, 478 m^3 and 633 m^3, respectively. Frequent droughts, floods and water logging hazards result in unstable agricultural production and a serious imbalance between water supply and demand (Liu et al. 2001, Liao et al. 2007).

Because of water limitations in the North and land constraints and high opportunity costs to labor in the South, our base scenario foresees limited scope for further improvements in production. The scenario puts a limit on land and water use to prevent further environmental degradation. Maize demand in China will increase substantially to 195 million tons in 2030 (up by 70% from 2000), mainly because of growth in per capita meat consumption as a result of income growth. Part of the additional demand can be met through productivity growth and slight area increase but even under optimistic yield growth assumptions imports must increase to 20 million tons from 2 million tons in 2004. Under such a scenario it is quite unlikely that the additional maize demand for biofuel can be met without further degrading water resources or major shifts of cropping pattern at the expense of other crops. More likely, under an aggressive biofuel program China will have to import more maize (or the crop displaced by maize), which will undermine one of its primary objectives, i.e. curbing import dependency.

Agricultural water use in India

Irrigation plays a major role in India's food supply. At present some 63% of the cereal production originates from irrigated areas. Wheat and rice are mostly produced under irrigated conditions while maize and other grains are grown in rainfed areas. Close to 85% of the area under sugarcane -the crop currently most used in bioethanol- is irrigated. It is estimated that the total harvested area amounts to 175 million hectares (in 2005) of which roughly 45% is irrigated. More than half of the irrigated area is under groundwater irrigation, mostly privately owned tubewells.

Total renewable water resources are estimated at 1887 km^3, but only half (or 975 km^3) is potentially utilizable. Total water resources amount to 2025 m^3 per capita (for the year 2000), or only around 1100 m^3 of potentially utilizable per capita supplies (Amarasinghe et al 2005). Water withdrawals in India were estimated at 630 km^3 in the year 2000, of which more than 90% was for irrigation. Spatial variation is enormous. The riverbasins of the Indus, Pennar, Luni and westerly flowing rivers in Kutsch and Gujarat are absolute water scarce, and much of North India suffers from groundwater overdraft (Amarasinghe et al. 2005). To address water scarcity, the government of India is exploring the possible implementation of a series of large scale interbasin transfers to bring water from water abundant to water short areas. This so-called "Linking of Rivers" project is controversial because it is ambitious and expensive; it will have adverse impacts on biodiversity and freshwater ecosystems, and will cause the displacement of millions of people. It is unlikely that this project will be fully implemented and operational in the near future. Our base scenario therefore foresees relatively limited scope for further irrigation development. The scenario adopts optimistic assumptions to improve productivity in both irrigated and rainfed agriculture.

Cereal and vegetable demand in India is projected to increase by 60% and 110% respectively from 2000 to 2030. The irrigated harvested area is expected to slightly increase from 75 to 84 million hectares. A major part of these increases will be met through improvements in yields though small increases of imports are inevitable. Sugarcane production increases from 300 to 605 million tons for food purposes. Our biofuels scenario implies that for the production of bioethanol an additional 100 million tons of sugarcane is needed, for which 30 km^3 additional irrigation water needs to be withdrawn. This amount will likely come at the expense of other irrigated crops (cereals and vegetables), which then need to be imported. For many years, the Indian government has focused on achieving national food self-sufficiency in staples. More recently, as the imminent danger of famines has decreased and non-agricultural sectors have expanded, the national perspective regarding production and trade has changed. But it is unclear if India would choose to import food to free up necessary resources to grow biofuel crops.

6) Summary and discussion

Summary

Biofuels are promoted for energy security, economic, political and environmental reasons. At present the role of biofuels in energy supply, and its implications for water and land use, are limited. But there are plans and policies in place around the world to increase biofuel production. However, even if all national policies and plans on biofuels are successfully implemented, they will have a relatively small impact on the global food system. Assuming that 7.5% of global gasoline demand will be met by biofuels by 2030 and no changes in conversion rates, 30 million additional hectares of crop land will be needed along with 180 km^3 of additional irrigation water withdrawals. Globally this is less than a few percentage points of the total area and water use. However, the impacts could be much larger for some individual countries including China and India with significant implications for water resources and with feedback into global grain markets. In fact it is unlikely that fast growing economies such as China and India will be able to meet future food, feed and biofuel demand without substantially aggravating already existing water scarcity problems, or importing grain, an outcome which counters some of the primary reasons for producing biofuels in the first place.

This analysis assumes no major changes in feedstock. Yet, this may become an important factor in the biofuel discussion. From a water perspective it makes a large difference whether biofuel is derived from fully irrigated sugarcane grown in semi-arid areas or rainfed maize grown in water abundant regions. The use of water-extensive oilseeds (such as Jatropha trees), bushes, wood chips and crop residuals (i.e. straw, leaves and woody biomass) is promising in this respect, though a few caveats are necessary. With existing technologies biofuel yields from Jatropha trees are fairly low (1500 liters of biodiesel per hectare at most), and processing is relatively expensive. Crop residuals, grass and tree leaves often are used as animal feed or organic fertilizer (compost), particularly in India where more than 90% of the energy intake comes from grass and crop residual (Kemp-Benedict 2006) and feed supplies are already short (ref?). Furthermore, the technology to convert woody biomass into biofuels (i.e. the use of enzymes to ferment straw into lignocellulosic bioethanol) is in development and not commercial yet (Heywood 2006).

Our analysis implicitly assumed that biofuels will become a cost-effective alternative to fossil fuels, because conversion technology will become more efficient while the crude oil price remains high. This may not be the case. Rather than shortage of proven crude oil supply, high oil prices are caused by political instability and bottlenecks in refinement capacity. These human induced factors may change, causing the oil price to drop to low levels where biofuels are economically infeasible.

Will an increase in biofuel demand lead to sustained higher food prices and adversely affect poor consumers in developing countries? There is some evidence that it might. Brown (2006) relates recent increase in corn prices to the opening of new biofuel plants. Rosegrant et al (2006) foresee substantial increases in food price in an aggressive biofuel scenario. But at a global level additional demand for agricultural commodities is small in comparison to projected food and feed demand. While some areas may face water and land limitations, others have sufficient spare capacity, provided that productivity improvements materialize (Molden et al forthcoming). Thus, production may take place in land and water abundant regions that are currently not involved in producing biofuels. Whether food prices are impacted will depend more on trade barriers, subsidies, policies and limitations to marketing infrastructure than lack of physical capacity.

Is it ethical to use food crops to produce energy, in a world where there are still 860 million people undernourished? Some authors voiced strong opinions against biofuels arguing that when poor consumers are pitched against rich car owners, the poor will loose out (Brown 2006, Pimentel 2003). But this statement needs nuance. The most commonly used biofuel crops are sugarcrops and maize. Sugar is a cash crop (not a staple) and may provide additional income to poor farmers. Maize is primarily used to feed animals to produce meat and milk. Globally 65% of all maize is used to feed animals; in the US it reaches 75%. With rising living standards and urbanization meat consumption will increase (it more than tripled in China over the past decades). So, the "unfolding global conflict over food"[10] will not be between cars and the poor, but rather between cars and carnivores.

[10] As eloquently worded by Brown 2006

Table 1: Biofuels land and water use (2005)

Bio-ethanol	bioethanol million liters [a]	main feedstock crop	*feedstock used million tons* [b]	area biofuel crop (million ha)	% total cropped area used for biofuels[c]	crop water ET (km3) [d]	% of total ET used for biofuel	irrigation withdrawals for biofuel crops (km^3)	% of total irrigation withdrawals for biofuels [e]
Brazil	15,098	sugarcane	167.8	2.4	5.0%	46.02	10.7%	17.75	48.5%
USA	12,907	maize	33.1	3.8	3.5%	22.39	4.0%	5.44	2.7%
Canada	231	wheat	0.6	0.3	1.1%	1.07	1.1%	0.08	1.4%
Germany	269	wheat	0.7	0.1	1.1%	0.36	1.2%	-	0.0%
France	829	sugarbeet	11.1	0.2	1.2%	0.90	1.8%	-	0.0%
ITALY	151	wheat	0.4	0.1	1.7%	0.60	1.7%	-	0.0%
Spain	299	wheat	0.8	0.3	2.2%	1.31	2.3%	-	0.0%
Sweden	98	wheat	0.3	0.0	1.3%	0.34	1.6%	-	0.0%
UK	401	sugarbeet	5.3	0.1	2.4%	0.44	2.5%	-	0.0%
China	3,649	maize	9.4	1.9	1.1%	14.35	1.5%	9.43	2.2%
India	1,749	sugarcane	19.4	0.3	0.2%	5.33	0.5%	6.48	1.2%
Thailand	280	sugarcane	3.1	0.0	0.3%	1.39	0.8%	1.55	1.9%
Indonesia	167	sugarcane	1.9	0.0	0.1%	0.64	0.3%	0.91	1.2%
S-Africa	416	sugarcane	4.6	0.1	1.1%	0.94	2.8%	1.08	9.8%
world ethanol	**36,800**			**10.0**	**0.8%**	**98.0**	**1.4%**	**43.6**	**1.7%**
biodiesel	1,980			1.2		4.7			0.0%
ethanol plus diesel	38,780			11.2	0.9%	102.7	1.4%	0	1.7%

a Dufey 2006

[b]conversion estimates from EIA 2004 table 3.1 page 53 and Dufey 2006, based on main crop used. The wide range in variation of both feedstock production efficiencies and conversion process efficiencies suggests that more work is needed in this area (IEA 2004).

[c] total cropped area estimated from WATERSIM model baseline year (see Fraiture 2006, and Fraiture et al. forthcoming)

[d] total ET estimated from WATERSIM model baseline year (ibid)

[e] total irrigation withdrawals estimated from WATERSIM baseline year (ibid)

Table 2: Gasoline and biofuels

	gasoline in billion liters per year[a]			biofuel contribution % energy equivalent		biofuels in billion liters		
	2002	*2030*	*annual growth %*	*2005*	*2030*	*2005*	*2030*	*annual growth %*
USA, Canada	500	667	1.0%	1%	5%	13.1	51.3	5.6%
EU	131	150	0.5%	2%	10%	3.8	23.0	7.5%
China	50	128	3.4%	3%	9%	3.6	17.7	6.5%
India	24	54	2.9%	3%	10%	1.7	8.3	6.4%
Africa	23	59	3.4%	1%	2%	0.4	1.8	6.0%
Brazil	17	35	2.5%	44%[b]	65%[b]	15.1[c]	34.5	3.4%
Indonesia	12	25	2.8%	1%	2%	0.2	0.8	6.3%
World	***1164***	***1747***	***1.5%***	***2.1%***	***7.5%***	***38.7***	***141.2*** [d]	***5.3%***

[a] based on IEA 2005. Conversion factors see: http://bioenergy.ornl.gov/papers/misc/energy_conv.html

[b] includes substantial exports of biofuels

[c] mainly South Africa

[d] Projections are in line with IEA 2004 and Rosegrant et al 2006

Table 3 Food and feedstock

crop	*global production for food and feed 2030, million tons*[a]	*need to meet biofuels demand, million tons*	*% increase to meet biofuel demand*
maize	890	177	20%
sugarcane	2,136	525	25%
rapeseed	64	51	80%

[a] CA scenario using WATERSIM model (see Fraiture 2006, and Fraiture et al. forthcoming)

Table 4: Biofuels land and water, projections for 2030

	biofuel in billion liters	*main feedstock crop*	*feedstock in million ton*	*national production for food and feed, 2030* [a]	*additional production for biofuels in %*	*area for biofuel crops million ha*	*% of total cropped area for biofuels* [b]	*crop ET for biofuels km3*	*% total crop ET for biofuels* [c]	*irrigation withdrawals for biofuel crops(km3)*	*% of total irrigation withdrawals for biofuels d*
USA, Canada	51.3	maize	131	316	42%	14.1	9%	76.0	11%	36.8	20%
EU	23.0	rapeseed	51	21	242%	14.6	28%	30.1	17%	0.5	1%
China	17.7	maize	45	175	26%	7.8	4%	43.6	4%	35.1	7%
India	9.1	sugarcane	101	613	16%	1.1	1%	21.6	3%	29.1	5%
S-Africa	1.8	sugarcane	20	29	70%	0.2		3.9	12%	5.1	30%
Brazil	34.5	sugarcane	384	513	75%	4.4	7%	86.3	14%	41.7	68%
Indonesia	0.8	sugarcane	9	41	21%	0.1	0%	2.5	1%	3.9	7%
World	***141.2***					***42.2***	***3%***	***261.5***	***3%***	***178.4***	***5%***

[b] total food-feed demand estimated from WATERSIM model CA scenario (see Fraiture 2006, and Fraiture et al. forthcoming)

[b] total cropped area is estimated from WATERSIM model CA scenario (ibid)

[c] total ET is estimated from WATERSIM model CA scenario (ibid)

[d] total irrigation withdrawals is estimated from WATERSIM CA scenario (ibid)

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